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# Search for prebiotic molecules in space

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**Abstract.** The search for prebiotic molecules in space is a part of an endeavour to solve the problem of how life originated on earth. The search includes multiwavelength observations and analysis of the spectrum from cold dark clouds, dense molecular clouds, pre-protostellar, protostellar and star forming regions, complemented with laboratory and mathematical simulations of the corresponding dynamical and chemical conditions. We are presently involved in studying the dynamics of the collapse of a typical molecular cloud core prior to a protostar formation, including chemistry involved with the evolution of the inorganic and organic molecules observed to be present in the dense molecular clouds.

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## 1. Introduction

The origin of life on earth is an unsolved problem that has attracted attention from very early times. In order to get it solved, the problem is presently being addressed from various angles. Geologists are searching for signs of earliest traces of life in ancient Precambrian rocks and meteorites. Chemists and biologists are trying to simulate the early atmospheric conditions on the earth in their laboratories to learn if the synthesis of prebiotic molecules are possible under such conditions. Infrared and microwave astronomers are engaged in analyzing the spectrum obtained from the interstellar medium (ISM), the molecular clouds, star-forming regions etc. in search of signatures of those molecules in space. Physicists and mathematicians are theoretically simulating various possible protostellar and early earth conditions to learn how simple inorganic and organic molecules would evolve with time under such conditions. In the subsequent sections we will get into the details of these various types of studies and finally outline the project that we have started working on as a part of this greater endeavour.

## 2. Laboratory simulations of the primordial earth

The search for the origin of life through laboratory experiments began with the Stanley Miller experiment of 1953. A big flask of boiling water was his primordial sea. Steam rising from the boiling water went up to a second flask where it mingled with methane, ammonia, hydrogen and water vapour, believed to be the gases of the early atmosphere. He used a Tesla coil to send blue sparks with the strength of 60000 volts to simulate lightning. After running the apparatus for a week he analyzed the chemicals in water and found it to be full of amino acids. This was the first time that amino acids were synthesized outside a living organism.

Miller's experiment has been carried forward with many variations. Recently Chris McKay at NASA's Ames research facility has been experimenting with an apparatus that replaces Miller's relatively weak Tesla coil with sparks of more than 200 thousand volts. He argues that it is not the electricity, but the shock wave generated in the atmosphere caused by lightning and thunder which is responsible for making new compounds. His experiment has yielded simple organic molecules - hydrogen cyanide (HCN), ethane ($C_2H_6$), ethylene ($C_2H_4$) - which McKay believes, represent some of earth's first steps towards life. In a gentler approach, David Usher of Cornell University uses a heat lamp to simulate 'day and night' conditions. The goal of his experiment is to learn about the synthesis of ribonucleic acid (RNA) in nature. David Deamer of the University of California at Davis recreates day-night cycles on a glass microscope slide. He is interested in the way the cell membrane might have formed [1].

## 3. Geological quests

A question of importance in the origin of life problem is how many billion years are necessary for the simple inorganic and organic molecules to organize through trial and error into complex organic molecules and finally evolve into life. The first primitive life molecules, if created on the earth was formed in a chemically reducing early atmosphere containing mainly $CH_4$, $H_2O$, $CO_2$ and $NH_3$. Oxygen was present only in small amounts produced by the breakdown of water vapour in the upper atmosphere. Mass production of free $O_2$ began only after the primitive life forms (the blue-green algae) appeared on earth and started photosynthesising. The initial bulk of this $O_2$ was consumed by soluble ferrous salts in the sea water to yield ferric salts $Fe_2O_3$.

$$4Fe^{2+} + O_2 + 4H_2O -----> 2Fe_2O_3 + 8H^+.$$

This process gave rise to enormous deposits of $Fe_2O_3$ under the sea which is thought to bear the evidence of the appearance of primitive life on earth. It has been discovered [2,3] based on the isotope ratios in carbon inclusions in one such 'banded iron' formation in Greenland that life existed on earth even before 3.85 billion years. The earth is estimated to have been created about 4.5 billion years ago. The discovery and subsequent dating of those ferric salt deposits have squeezed the time gap between the formation of the earth and the appearance of life to less than a billion year. This time gap available for life to develop from scratch on the earth, is argued by some to be very short on a geological scale. Geologists are still in search of evidences of even earlier records of appearance of life on earth. These developments have primarily encouraged people to question whether, along with simple molecules like $CH_4$, $NH_3$ etc., some complex organic ingredients could also be present on earth during the initial period of its existence.

In 1969, a carbonaceous meteorite fell near Murchison in Australia. NASA scientists analyzed some of its fragments and determined that they contained organic materials [4,5]. In 1984, micrographs were taken from the fragments of the same meteorite, which showed forms resembling fossilized cells and virus particles [6]. Controversy however remains as many scientists are of opinion that those could be earthly contaminants. The meteorite from Mars $ALH84001$ is presently under investigation by NASA which is now applying more accurate experimental techniques that take care of the contamination factor. The results of their investigations have not been published yet.

Whether meteorites contain fossils or not, is a matter which has to be settled through further investigations, but what is definitely established as a fact is that, a group of meteorites, called carbonaceous chondrites, definitely contain different kinds of amino acids.

## 4. Spectral observations

Given that amino acids are complex organic molecules essential to life and they are present in objects coming from space, it naturally follows that biologically important molecules should be present somewhere in space. Multiwavelength observations are being carried on in search of organic molecules in space from earth and satellite based instruments. A large number of molecules have been detected in the molecular cloud complex of Sagittarius $B_2$. Among the discovered species, there is methyl alcohol ($CH_3OH$), formic acid (HCOOH), formamide ($NH_2CHO$), methyl amine ($CH_2NH$) etc. [7].

$CH_3OH$ has also been observed in Orion KL representing hot dense molecular cores, but not in either TMC-1 representing dust clouds or IRC+10216, representing carbon star envelops [8]. There are some reports stating that measurable amounts of glycine ($H_2NCH_2COOH$) the simplest amino acid, may be present in the interstellar medium. This has not been confirmed yet. The

UMIST database for Astrochemistry, 1995 [9] has given the list of the observed interstellar and circumstellar molecules, which shows that the total number of observed organic species is 70 with neutral molecules containing upto 12 atoms.

## 5. Stellar events simulated in laboratory

Bernstein and others have conducted a very interesting series of experiments in the laboratory [10]. They prepared interstellar ice analogs containing $H_2O$, $CH_3OH$, $CO$ and $NH_3$ in ratios consistent with the infrared spectra of ices in dense molecular clouds. Ice samples were then irradiated with UV and subsequently warmed in stages to simulate a stellar event. The infrared spectra of the photolysed sample detected the presence of the formyl radical (HCO), formaldehyde (HCHO), several nitriles (XCN), and also HMT (hexamethyl tetramine: $C_6H_12N_4$). According to them, HMT can act as a possible source of amino acids in the ISM.

## 6. Mathematical simulations

Just as people are simulating stellar events in the laboratory, mathematical simulations of molecular cloud collapse prior to protostar formation are being tried by many researchers. The object is to learn the fate of the molecules already present in the ISM during various stellar events. Evidently, a successful modeling requires the coupling of chemical and multidimensional hydrodynamical codes. The most widely adopted dynamical code for studying chemistry is the time-dependent density of the Shu [11] CEW model for isothermal collapse. Basu and Mouschovias [12] examined the formation of dense cloud core including the diffusion of magnetic flux from the central regions of the core. Bergin and Langer [13] have modeled the evolution of molecules including $CO$, $HCHO$, $HCO^+$, $NH_3$, $HCN$ etc. Although 3864 reactions among 395 species with their rate coefficients are known, they do not lead to the biologically most wanted molecules, namely, the amino acids, purines and the pyrimidines. The possibility of the formation of these molecules in the dense molecular clouds and the subsequent star formation process remains to be investigated. In the laboratory, the amino acid alanine ($CH_3CHNH_2COOH$) can be produced by the reactions between $CH_3CHO$, $NH_3$, $HCN$ and $H_2O$. The reaction mechanism is,

$$CH_3CHO + HCN - - - - - - - > CH_3CHOHCN \qquad \text{(cyanohydrin)}$$

$$CH_3CHOHCN + NH_3 - - - - > CH_3CHNH_2CN + H_2O$$

$$CH_3CHNH_2CN + 2H_2O - - - - - - - - - > CH_3CHNH_2COOH + NH_3.$$

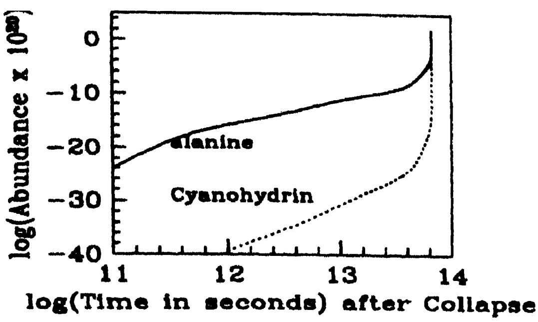


**Figure 1.** Variation of abundance of cyanohydrin and alanine in a molecular cloud collapse [15] as a function of time (in seconds). Both are in logarithmic scale.

All these ingredients are available in dense molecular clouds. But whether synthesis of this compound is possible during any stellar event is not yet known. Experimental data also show that amino acids can be synthesized by quenched shock heating of reduced gases.

Comets are also presumed to be probable candidates where reactions between organic molecules can advance to a great extent. Inside the comet head the complex molecules if formed, could remain protected from cosmic ray bombardment, and the cometary ice grains could act as catalysts for more reactions. The low temperature formaldehyde reactions and build up of organic molecules in comets and interstellar ices are being investigated by Schute and others [14]. Hoyle and Wickramsinghe have gone a step further to argue very strongly that not only the complex organic molecules, but life itself had been created in outer space and came to earth through comets asteroids etc. The scientific community however is not ready to accept this view.

The project that we have started working on is based on a very simple assumption. It is that our earth is no special place in the universe. The events responsible for the appearance of life on earth should be deducible from the conditions and processes which occurred during the evolution of a molecular cloud to a protostar and from there to a star with a planetary system. Presently, the hydrodynamic equations governing the formation and evolution of these systems are being combined with molecular species formation. Among other things we also include amino acid synthesis and urea synthesis in the network. A typical simulation [15] result which shows the abundance of cyanohydrin (solid) and amino acid (dashed) in a molecular cloud collapse (initial condition: $\rho = 10^{-22}$gm cm$^{-3}$ at $r = 10^{18}$cm. $v \propto r^{-1/2}$, $\rho \propto r^{-3/2}$ as in free fall. T=20K till $r = 10^{15}$cm and $\propto r^{-1}$ till $r = 10^{13}$cm where simulation is stopped.). The abundance for cyanohydrin is particularly significant in this run. These products are expected to be in protostellar clouds and eventually to planets during their formation.

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## References

1. S J Baum *Planet Earth* (New York : Macmillan Publishing) (1982)
2. A Mojzsis et al. *Nature* **384** 55 (1996)
3. H D Holland *Science* **275** 38 (1997)
4. A Keith et al. *Nature* **228** 923 (1970)
5. F Hoyle and C Wickramsinghe *Life cloud : the origin of life in the universe* (Harper and Row Publishing Co.) (1978)
6. C Wickramsinghe ed. *Fundamental Studies and the Future of Science* (University College Cardiff Press) (1984)
7. B Basu *An Introduction to Astrophysics* (Prentice-Hall India) (1997)
8. K Rohlfs and T L Wilson *Tools of Radio Astronomy* (Springer-Verlag, Berlin) (1996)
9. T J Miller et al. *Astron. Astrophys. Suppl. Ser.* **121** 139 (1997)
10. M P Bernstein, S A Sandford, L J Allamandola and S Chang *Astrophys. J.* **454** 327 (1995)
11. F H Shu *Astrophys. J.* **214** 798 (1977)
12. S Basu and T Mouschovias *Astrophys. J.* **432** 720 (1994)
13. E A Bergin and W D Langer *Astrophys. J.* **486** 316 (1997)
14. W A Schute et al. *Adv. Sp. Res.* **15(3)** 401 (1995)
15. S K Chakrabarti and S Chakrabarti (1999) *Astrophys. J.* (submitted)